CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-199

LITTLE LAKE AND AIRPORT LAKE FAULT ZONES
INYO AND KERN COUNTIES, CALIFORNIA

by

Christopher J. Wills
Associate Geologist
November 18, 1988

INTRODUCTION

The Little Lake and Airport Lake fault zones are two active fault zones in the southwest corner of the Basin and Range geologic province. The Coso Range (Figure 1) and adjacent valleys east of the Sierra Nevada frontal fault are extending in an east-west direction and faults are distributed over a broad area. Both the Little Lake and Airport Lake faults cut late Pleistocene volcanic rocks (Duffield and Bacon, 1981; Roquemore, 1981). Both faults extend southward from the Coso Range into the alluvial basin of Indian Wells Valley (Figure 1). Roquemore and Zellmer (1987) have mapped "active fault features" across the China Lake Naval Weapons Center and through the City of Ridgecrest.

The Little Lake and Airport Lake faults are active and lie within the current Basin and Range study region. They are evaluated here for possible zoning under the Alquist-Priolo Special Studies Zones Act (Hart, 1985). Portions of these faults within the Little Lake, Volcano Peak, Airport Lake, Pearsonville, White Hills, Inyokern, Ridgecrest North and Ridgecrest South 7.5-minute quadrangles are evaluated here. Portions of the Sierra Nevada fault zone on these quadrangles are also evaluated here. Part of the Airport Lake fault zone and many additional unnamed faults occur north and east of this area on three or four additional quadrangles. Time does not permit their evaluation. These faults lie entirely on the Naval Weapons Center where they are not likely to be a hazard to development.

SUMMARY OF AVAILABLE DATA

The Little Lake and Airport Lake faults were first mapped in detail by von Huene (1960) as part of a Ph.D thesis, which emphasized the large-scale structure of the area shown by a gravity survey. Von Huene recognized the Little Lake fault as a right-lateral strike slip fault, as well as many normal faults of the Airport Lake zone. More recent work has emphasized the Quaternary volcanism (Duffield and Bacon, 1981) and tectonics (Roquemore, 1981; Roquemore and Zellmer, 1987).

Little Lake fault

The Little Lake fault is a right-lateral strike-slip fault which offsets Pleistocene lava flows in the southwestern Coso Range and extendsto the south as a series of en echelon faults (Figure 1). In Indian Wells Valley the Little Lake apparently merges with the Airport Lake fault. The major faults of Indian Wells Valley have been called the Little Lake fault (Roquemore, 1981; Roquemore and Zellmer 1983, 1987) though they are continuous with the Airport Lake fault zone and have similarities to both zones. For consistency with previous work, the northwest trending zone in Indian Wells Valley is described here as part of the Little Lake fault. Measured from west of the town of Little Lake to south of Ridgecrest, the Little Lake fault is about 40 km long. The fault merges with the Sierra Nevada fault zone to the north. To the south, expression of faulting dies out in the alluvium of Indian Wells Valley.

Previous maps of the northwestern portion of Little Lake fault (von Huene, 1960; Duffield and Bacon, 1981; Roquemore, 1981) use the Little Lake and Mountain Springs Canyon 15-minute quadrangles as base maps. To eliminate errors in data transfer and due to differences in interpretation, their fault traces are not shown on the Little Lake and Volcano Peak 7 1/2-minute quadrangles. Rather, the traces are plotted directly from aerial photographs interpreted for this study (Figures 2a and 2b).

In the Coso Range the fault crosses the nearly horizontal surface of a 399,000 +_ 45,000 year old basalt flow (Duffield and Bacon, 1981 [Figure 2a]). On the surface of this flow the fault steps to the right three times, in each case creating a pull-apart depression (von Huene, 1960; Roquemore, 1981) (Figure 2a,b). Northwest of this basalt flow the Little Lake fault deflects the Pleistocene channel of the Owens River and offsets two basalt flows which flowed down the channel (Figure 2a) (Duffield and Smith, 1978). One of these flows was dated as 140,000 +_ 89,000 years and the other contained too little radiogenic argon to be dated (Duffield and Bacon, 1981). The age of this youngest flow has been estimated at 22,000 years based upon a constant rate of canyon downcutting between 10,000 and 130,000 years B.P. (Duffield and Smith, 1978). Northwest of the Pleistocene Owens River channel the Little Lake fault crosses beneath Highway 395 and can be traced to the northwest in rocks of the Sierra Nevada Batholith. At the north end of the trace the Little Lake fault may merge with the Sierra Nevada frontal fault (Roquemore, 1981).

Roquemore (1981) estimated 250 m of offset on the channel of the Pleistocene Owens River. The apparent offset has been increased by slumping from the ridge between the fault and the channel wall (Roquemore, pers. comm., 1988) and is probably less than 250 m. This offset occurs in the side of a channel cut in basalt that has been dated at 399,000 +_ 45,000 years B.P. The channel pre-dates an intra canyon lava flow dated 140,000 +_ 89,000 years B.P. Because the age of the channel is poorly constrained, slip rate based on offset of the channel wall is loosely constrained between .6 and 1.8 mm/yr. More recent work by Roquemore (1988), based on offsets of the intra canyon lava flows and fault morphology, suggests a slip rate "as high as 1 mm/yr or greater".

Playa sediments in one of the pull-apart depressions were trenched by Roquemore (1981) (locality 1, Figure 2a). There, a 4 m wide zone of faulting was found to dip to the southwest. The faulting appeared to extend to the ground surface. A layer between 1 and 3 meters below the surface contained carbonized twigs and charcoal that was radiocarbon dated 2545 $\pm$ 160 years. This layer also contained open fracture fillings interpreted to be liquefaction features ("mud volcanos") by Roquemore (1981).

Two earthquakes of magnitude M_L 5.2 have occurred in the northern Indian Wells Valley near the intersection of the Airport Lake fault and the Little Lake fault. Roquemore and Zellmer (1983) mapped ground cracking along several en echelon scarps within the Little Lake fault zone caused by the 1982 earthquake. The ground cracking occurred as extensional fractures along the crest of monoclinal flexures within the alluvium. One monoclinal flexure was trenched and a fault was found in alluvium or lacustrine layers at a depth of 4 m.

Airport Lake fault zone

The Airport Lake fault zone is a broad zone of north-south trending normal faults over 50 km long. A right lateral component of movement is indicated by offset stream channels (Roquemore, 1981) and earthquake first motions (Walter and Weaver, 1980). The southern half of this zone, on the Volcano Peak, White Hills and Ridgecrest North quadrangles (Figures 2b,d and f) is evaluated here. Faults generally define the west side of the Coso Basin graben (Figure 2b), cross the White Hills and intersect or merge with the Little Lake fault in Indian Wells Valley (Figure 1). Total offset across the fault is approximately 600 m (Roquemore and Zellmer, 1987). Units offset along this zone of faults include the Plio-Pleistocene White Hills Formation, a basalt flow dated at 188,000 $\pm$ 35,000 years B.P. (Duffield and Bacon (1981), and the alluvium of Indian Wells Valley. The alluvium of Indian Wells Valley includes Holocene fan, playa, and aeolian deposits thinnly covering Pleistocene alluvial deposits (Moyle, 1963). Moyle mapped outcrops of older alluvium on the margins of Indian Wells Valley northwest and southwest of Ridgecrest. All of these units have been offset by faults of the Airport Lake or Little Lake zones.

Scarp morphology studied by Roquemore (1981) suggests a very recent origin of several scarps within the Airport Lake fault zone. Roquemore (1981) calculated scarp ages using the method of Wallace (1977). Ages of approximately 40 years are clearly incorrect (Roquemore, 1981), since there are no historic records of large surface rupture in the area, but illustrate the "fresh" morphology of the scarps. Roquemore trenched across one of the more prominent scarps of the Airport Lake fault zone at locality 2, figure 2b. A steep, eastward-dipping, normal fault offsets several alluvial units and the ground surface. One alluvial unit exposed in this trench contained obsidian clasts that could be correlated with 90,000 year B.P. rhyolite domes (Bacon, 1979 pers. comm. to Roquemore). Roy J. Shlemon considered the upper alluvial unit to be Holocene (pers. comm. to Roquemore), apparently based on its lack of soil development.

Sierra Nevada fault zone

Parts of the Sierra Nevada fault zone cross the Inyokern and Little Lake quadrangles (Figures 2a and e). The Sierra Nevada fault zone is a major, range bounding normal fault that separates the Sierra Nevada geologic province from the Basin and Range geologic province. This fault has been known to exist along the west side of Indian Wells Valley since at least 1938 (Jenkins, 1938). Further detail was shown by Von Huene (1960) and Jennings and others (1962). In Rose Valley, in the Little Lake quadrangle (Figure 2a), the faults along the trend of the Little Lake fault, but parallel to the Sierra Nevada are shown as the Sierra Nevada fault zone by Duffield and Bacon (1981). These faults offset young alluvium as mapped by Duffield and Bacon (1981). Slip rates have not been determined for this portion of the Sierra Nevada fault zone, but the prominent fault line scarp of the Sierra Nevada does suggest relatively large displacement.

SEISMICITY

Seismicity in the Indian Wells Valley - Coso Range area is shown on Figure 3. Only well-located earthquakes (A and B quality) are shown. Epicenters for the period 1969 to 1985 are depicted based on data from the California Institute of Technology (1985).

This plot includes the MOL? 5.2 earthquake of 10/01/82. Earthquakes of similar magnitude occurred along the Little Lake fault in 1938 and 1961. The larger clusters of earthquakes occur near the intersection of the Little Lake and Airport Lake faults. The northwestern part of the Little Lake fault is relatively quiet, seismically. The wide scatter of small events in the northern half of the area may be in part due to weapons testing on the China Lake Naval Weapons Center.

A study of the seismicity of the Coso Range and adjacent areas by Walter and Weaver (1980) shows a similar pattern of earthquakes for the period 9/75 to 9/77. First motion studies show both normal and right-lateral focal mechanisms along a roughly north-south trend in Indian Wells Valley and throughout the Coso Range.

REVIEW OF AERIAL PHOTOGRAPHS AND FIELD CHECKING

Geomorphic evidence for Holocene faulting was interpreted on aerial photographs and plotted on 7.5-minute topographic maps

(Figure 2). Aerial photographs taken by the USDA in 1940 and 1953 were used for the majority of the area. USGS photos taken in 1961 and 1976 were used in some areas. John Zellmer and Glenn Roquemore of the China Lake Naval Weapons Center generously loaned 1/12,000 scale, color, low sun angle photos taken in 1981. These only covered parts of the area, but were most useful for checking some of the less obvious features.

On the Pearsonville, White Hills, Inyokern, Ridgecrest North and Ridgecrest South quadrangles active fault maps prepared by Roquemore and Zellmer (1987) were used (Figures 2c,d,e,f and g). Fault related geomorphology plotted by Roquemore and Zellmer was checked and some additional fault related geomorphology was plotted. In some cases, faults plotted by Roquemore and Zellmer appeared to be mislocated. Others were not defined by geomorphic evidence visible on the available aerial photos. These are marked "not-verified" on the accompanying maps (Figures 2c,d,e,f and g).

Portions of the Little Lake, Airport Lake and Sierra Nevada fault zones were field checked on June 16 and 17, 1988. John Zellmer and Glenn Roquemore of the China Lake Navel Weapons Center arranged access to the center and provided assistance in the field. Two localities along the Airport Lake fault zone were visited on a GSA, Cordilleran Section field trip led by Wendell Duffield and Glenn Roquemore on March 28, 1988.

Geomorphic evidence for recently active faulting is shown on Figures 2 a-g and is summarized below.

Little Lake fault

This fault is very clearly defined from west of the village of Little Lake southeast for slightly over 10 km (Figures 2a,b and c). In rocks of the Sierra Nevada batholith and older alluvium west of Little Lake, the fault is defined by aligned springs and right-laterally deflected drainages. South of Little Lake, the fault crosses the late Pleistocene channel of the Owens River, offsetting a lava flow which is approximately 22,000 years old (Duffield and Smith, 1978), and the wall of the channel (Figure 2a).

Southeast from the Owens River channel the Little Lake fault crosses the surface of a late Pleistocene lava flow (399,000 $\pm$ 45,000 years B.P., Duffield and Bacon, 1981) (Figure 2a,b, and c). On the surface of this flow, the fault is clearly defined by a series of linear scarps and troughs and pull-apart basins. Three pull-apart basins of approximately equal size along the trace of the fault suggest that the slip on the fault is approximately constant along its length. The sharpest of these pull-apart basins is approximately 400 m long (figure 2a). Four hundred meters offset of a 400,000 year old flow yields a slip rate of 1 mm/year.

On the Pearsonville quadrangle (Figure 2c), the continuous surface trace of the Little Lake fault ends. Over 2 km to the southeast the Little Lake fault intersects the Airport Lake fault zone and surface expression of the Little Lake fault begins again. The Little Lake fault to the southeast offsets Holocene alluvial and aeolian deposits on the floor of Indian Wells Valley. Faulting is expressed as left-stepping en echelon scarps or warps along a northwest trend.

To the south, the Little Lake fault becomes less well defined. Scarps on the Ridgecrest North quadrangle are generally lower and less sharp than those on the Pearsonville quadrangle. This may reflect decreasing activity on the fault zone to the south or an increased rate of sedimentation. The southern end of the Little Lake fault is expressed as a series of well-defined, left-stepping tonal features in a plowed field on the southeast side of Ridgecrest (Section 3, R40E, T27S) (Figure 2g). These features may represent soil-filled fissures related to right-lateral surface rupture.

Deflected drainages and springs clearly delineate the Little Lake fault zone west of Highway 395 to a saddle west of the village of Little Lake (Figure 2a). To the north of this saddle the fault apparently trends north through a saddle and a bench on the next two ridges. The fault is poorly defined across the intervening canyons. North of the bench, a west facing scarp trending due north is the last well-defined part of the Little Lake fault. Faults north of this point parallel the Sierra Nevada are considered part of the Sierra Nevada fault zone (Duffield and Bacon, 1981) and are discussed below.

Scarps near the intersection of the Airport Lake and Little Lake faults and along the Little Lake fault to the southeast were field checked on June 16 and 17, 1988. At locality 4, Figure 2f, on the Ridgecrest North quadrangle, a fault exposed in the wall of a gravel pit was observed on June 16, 1988. This fault offsets late Pleistocene or Holocene alluvium to within 1 foot of the ground surface. Exposures were not adequate to determine if any alluvial layers were unfaulted.

In the City of Ridgecrest, fault related geomorphology has been largely obscured by grading and construction. No features clearly indicative of Holocene faulting were observed, although broad warps and depressions were evident.

Airport Lake fault zone

The Airport Lake fault zone consists of many north-south trending normal faults in a zone over 50 kilometers long. Faults are clearly defined in late Pleistocene and Holocene alluvial materials on the west side of Coso Basin, late Pleistocene basalt flows in the southern Coso Hills and late Pleistocene and Holocene alluvium in the Indian Wells Valley. The faults occur in a narrow zone along the west side of the Coso Basin (Figure 2b), but the zone widens to the south, reaching a maximum width of over 8 km in the northern Indian Wells Valley (Figure 2c,d).

Scarps trend generally north-south and have vertical offsets. Scarps are particularly fresh in resistant Late Pleistocene basalt but are also prominent in latest Pleistocene and Holocene lacustrine and alluvial deposits in Indian Wells Valley.

Faults were observed on March 28 and June 17, 1988 in trenches excavated for fault studies by Roquemore and Zellmer. On the Volcano Peak quadrangle (locality 2, Figure 2b), a trench shows offset of alluvium of probable Holocene age (Roquemore, 1981) and of the alluvial fan surface. On the White Hills quadrangle, two parallel faults, approximately 5 meters apart, offset latest Pleistocene or Holocene lacustrine deposits at locality 3 figure 2d. One of these faults can be traced at the surface as a "mole track". Mole tracks in this area have the same form as mole tracks along other faults and are up to 1 meter wide and 30-40 cm high. They apparently form by minerals precipitating from groundwater along the fault, causing expansion of soils in the fault zone. The "mole tracks" are therefore not by themselves indications of recent movement but do represent fault zones and groundwater barriers that extend to the ground surface.

Sierra Nevada fault zone

The Sierra Nevada fault zone is expressed on the Little Lake and Inyokern quadrangles as a series of tonal lineaments, vegetation contrasts and generally degraded scarps. On the Little Lake quadrangle (Figure 2a), breaks-in-slope and tonal lineaments cross alluvial fans. These fans have been mapped by Duffield and Bacon (1981) as young alluvium of late Pleistocene to Holocene age. The lack of preservation of depositional bars and swales on most surfaces suggests that most of the fan surfaces are of late Pleistocene age. The fault scarps are relatively subtle and discontinuous, reflecting either a long period of inactivity or a low slip rate.

On the Inyokern quadrangle (Figure 2e), scarps over 20 m high with maximum slope angles of about 20° were measured by Roquemore and Zellmer (1987) in older alluvium. These scarps were field checked on June 17, 1988. Three distinct slope angles were observed and, although lateral erosion may have contributed to the steepest slope, repeated fault rupture has probably occurred.

CONCLUSIONS

The Little Lake and Airport Lake fault zones are two significant zones of active faulting in the southwestern basin and range. They are apparently responding to regional extension of the area in very different ways.

Little Lake fault

The Little Lake fault is a right-lateral strike-slip fault which is well defined on the surfaces of Late Pleistocene basalt flows. Rhombic depressions on the surface of a 400,000 year old basalt flow are about 400 m long (Figure 2a). The maximum slip rate on the fault is thus about 1 mm/year. This is consistent with slip rates based on offset of the channel of the Pleistocene Owens River and on offset of a 22,000 year old basalt flow (Roquemore, 1988).

The Little Lake fault is well defined from west of the village of Little Lake for over 40 km to the southeast. Surface expression of the fault becomes discontinuous in the Indian Wells Valley. En echelon normal faults of this zone offset late Pleistocene and Holocene alluvial deposits. These faults extend through the City of Ridgecrest. Earthquakes of approximate magnitude 5 have occurred near the intersection of the Little Lake and Airport Lake faults in 1982 and 1961 and to the southeast in 1938. Surface cracking occurred during the earthquake in 1982 (Roquemore and Zellmer, 1983). En echelon tonal features (probable soil filled fissures) on the Ridgecrest south quadrangle also impy recent surface rupture in a right-lateral sense.

Airport Lake fault zone

The Airport Lake fault zone is a broad zone of north-trending normal faults over 50 km long. A right lateral component is indicated by en echelon faults in parts of the zone, right laterally offset stream channels (Roquemore, 1981) and first motion studies (Walter and Weaver, 1980). Only the southern half of the fault zone is evaluated here. Within the study area the fault zone bounds the east side of the Coso Range, crosses the White Hills and extends extends into Indian Wells Valley, where it intersects the Little Lake fault. On the Volcano Peak quadrangle, it is a narrow zone of well defined scarps. The zone widens to the south were it consists of many normal faults in Pleistocene basalt and alluvium. Slip rates have not been calculated for this fault but it is clearly active. Fault offset of Holocene or latest Pleistocene alluvial layers has been observed in trenches in the Volcano Peak, and White Hills quadrangles.

Sierra Nevada fault zone

Portions of the Sierra Nevada frontal fault cross the Little Lake and Inyokern quadrangles. On the Little Lake quadrangle (Figure 2a), the fault is defined by scarps, breaks-in-slope and tonal lineaments on alluvial surfaces of probable late Pleistocene age. The discontinous and degraded features in this area indicate late Quaternary displacement. There is no clear evidence of Holocene activity, although minor displacements cannot be ruled out. On the Inyokern quadrangle (Figure 2e), well-defined scarps probably represent Holocene surface rupture but may have been erosionally modified.

RECOMMENDATIONS

The Little Lake, Airport Lake, and Sierra Nevada faults are sufficiently active and well defined for zoning under the Alquist-Priolo Act (Hart, 1985). The fault strands recommended for zoning are highlighted in yellow on Figure 2a,b,c,d,e,f, and g. References cited on the zone maps should be Duffield and Bacon (1981) and this FER on the Little Lake and Volcano Peak quadrangles. Roquemore and Zellmer (1987) and this FER should be cited on the Pearsonville, White Hills, Inyokern, Ridgecrest North and Ridgecrest South quadrangles.

C.J. Wills

Christopher J. Wills
Associate Geologist
R.G. #4379

Reviewed & approved
Earl W. Hart
3/29/89

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